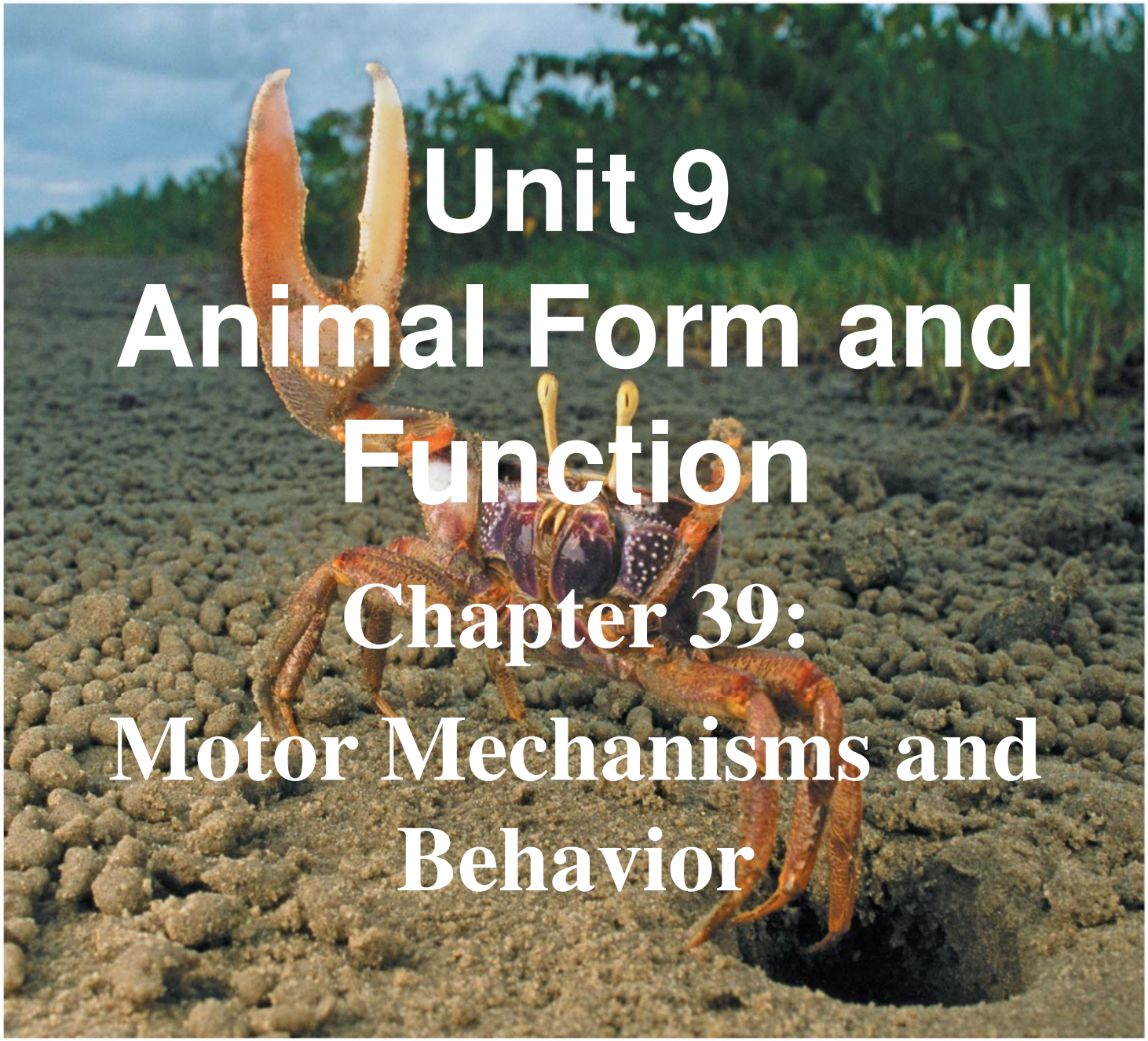


Unit 9
Animal Form and Function

Chapter 39:
Motor Mechanisms and Behavior

Overview: The How and Why of Animal Activity

- A **behavior** is an action carried out by muscles under control of the nervous system
  - Essential part of
    - Acquiring nutrients
    - Finding a partner for reproduction
    - Homeostasis
  - Behavior is subject to natural selection

Concept 39.1: The physical interaction of protein filaments is required for muscle function

- Muscle activity is a response to input from the nervous system
  - Muscle contraction is an active process powered by chemical energy
  - Muscle relaxation is passive
- Muscle cell contraction relies on the interaction between protein structures
  - **Thin filaments** consist of two strands of actin coiled around one another
  - **Thick filaments** are staggered arrays of myosin molecules

Vertebrate Skeletal Muscle

- Vertebrate **skeletal muscle** moves bones and the body
  - Characterized by a hierarchy of smaller and smaller units
- A skeletal muscle consists of a bundle of long fibers, each a single cell, running parallel to the length of the muscle
- Each muscle fiber is itself a bundle of smaller **myofibrils**
  - Contain thick and thin filaments
  - Made up of repeating sections called **sarcomeres**
    - Basic contractile units of skeletal muscle

- Skeletal muscle is also called striated muscle because the regular arrangement of myofibrils creates a pattern of light and dark bands
- Thin filaments attach at the end of sarcomeres
  - Z lines
- Thick filaments are anchored in the middle
  - M line
- In a muscle fiber at rest, thick and thin filaments partially overlap
  - Edge only has thin actin filaments
  - Center contains only thick myosin filaments

Figure 39.2a

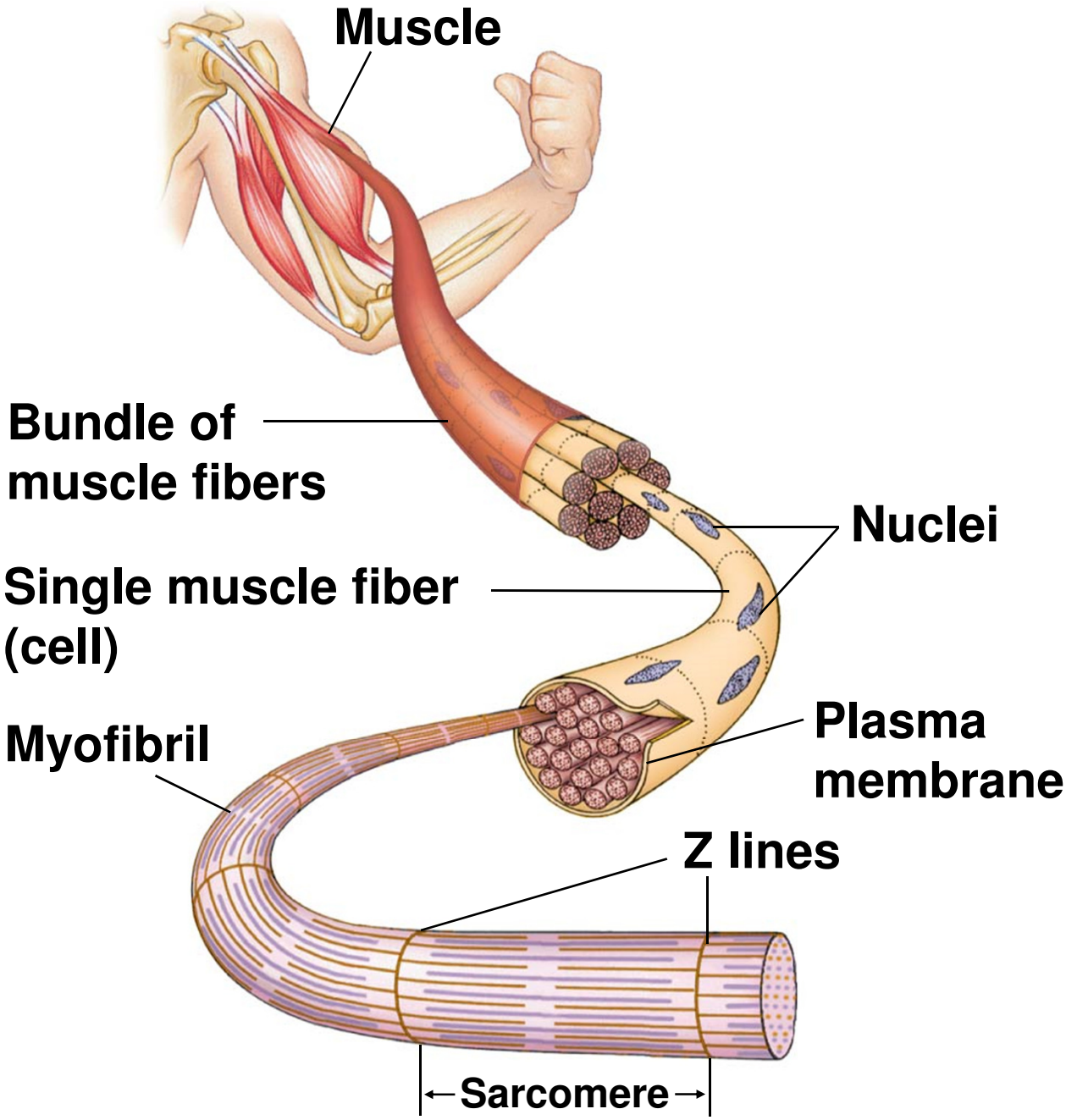
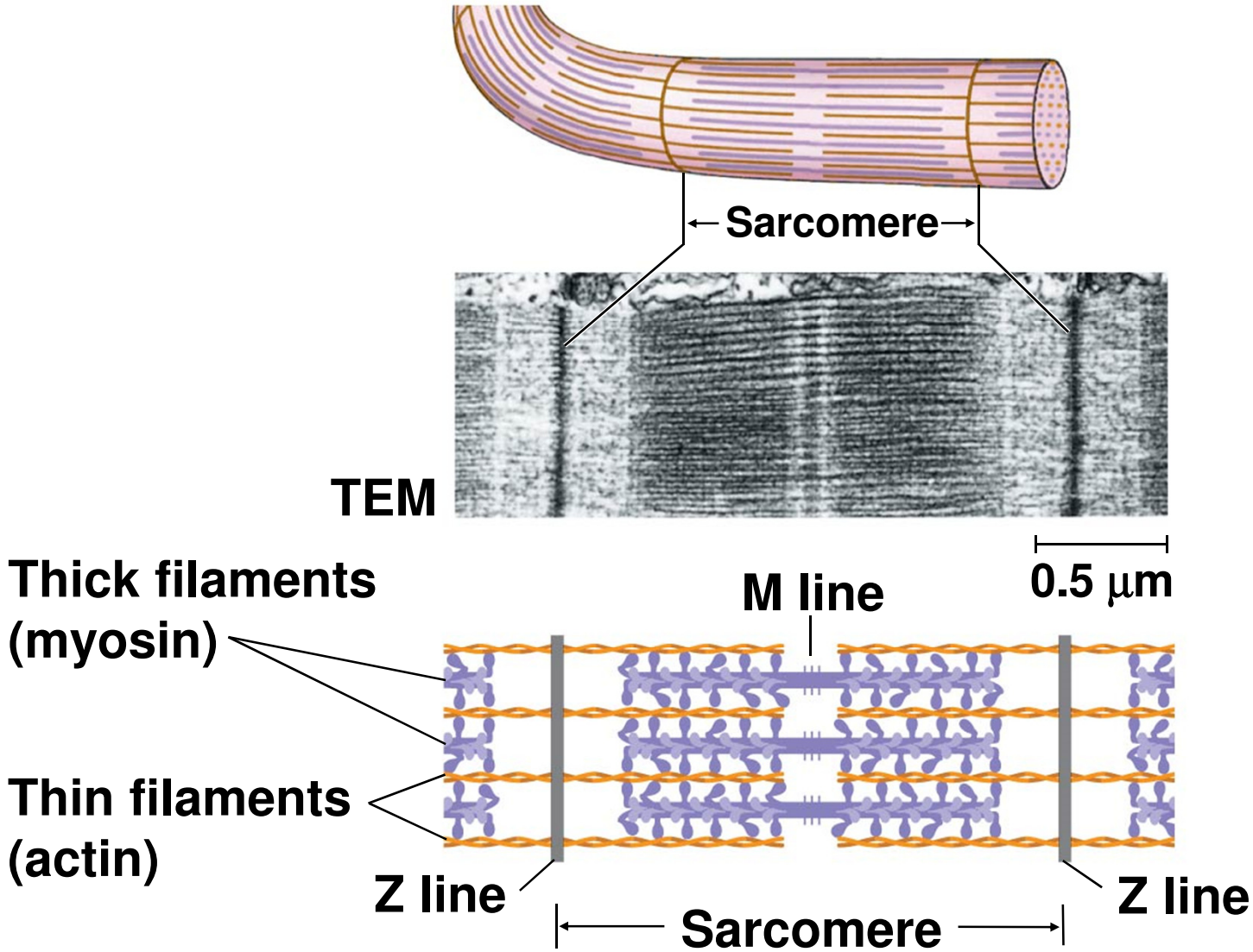

Muscle
Bundle of muscle fibers
Nuclei
Single muscle fiber (cell)
Plasma membrane
Myofibril
Z lines
Sarcomere

Figure 39.2b


Sarcomere
TEM
0.5 μm
Thick filaments
(myosin)
M line
Thin filaments
(actin)
Z line
Z line
Sarcomere

The Sliding-Filament Mechanism of Muscle Contraction

- A contracting muscle shortens
  - But the filaments stay the same length!
- According to the **sliding-filament model**, filaments slide past each other longitudinally, causing an overlap between thin and thick filaments
  - The sliding of filaments relies on interaction between actin and myosin

- The “head” of a myosin molecule binds to an actin filament, forming a cross-bridge
  - Pulls the thin filament toward the center of the sarcomere
- Muscle contraction requires repeated cycles of binding and release
- Glycolysis and aerobic respiration generate the ATP needed to sustain muscle contraction

CAMPBELL BIOLOGY IN FOCUS

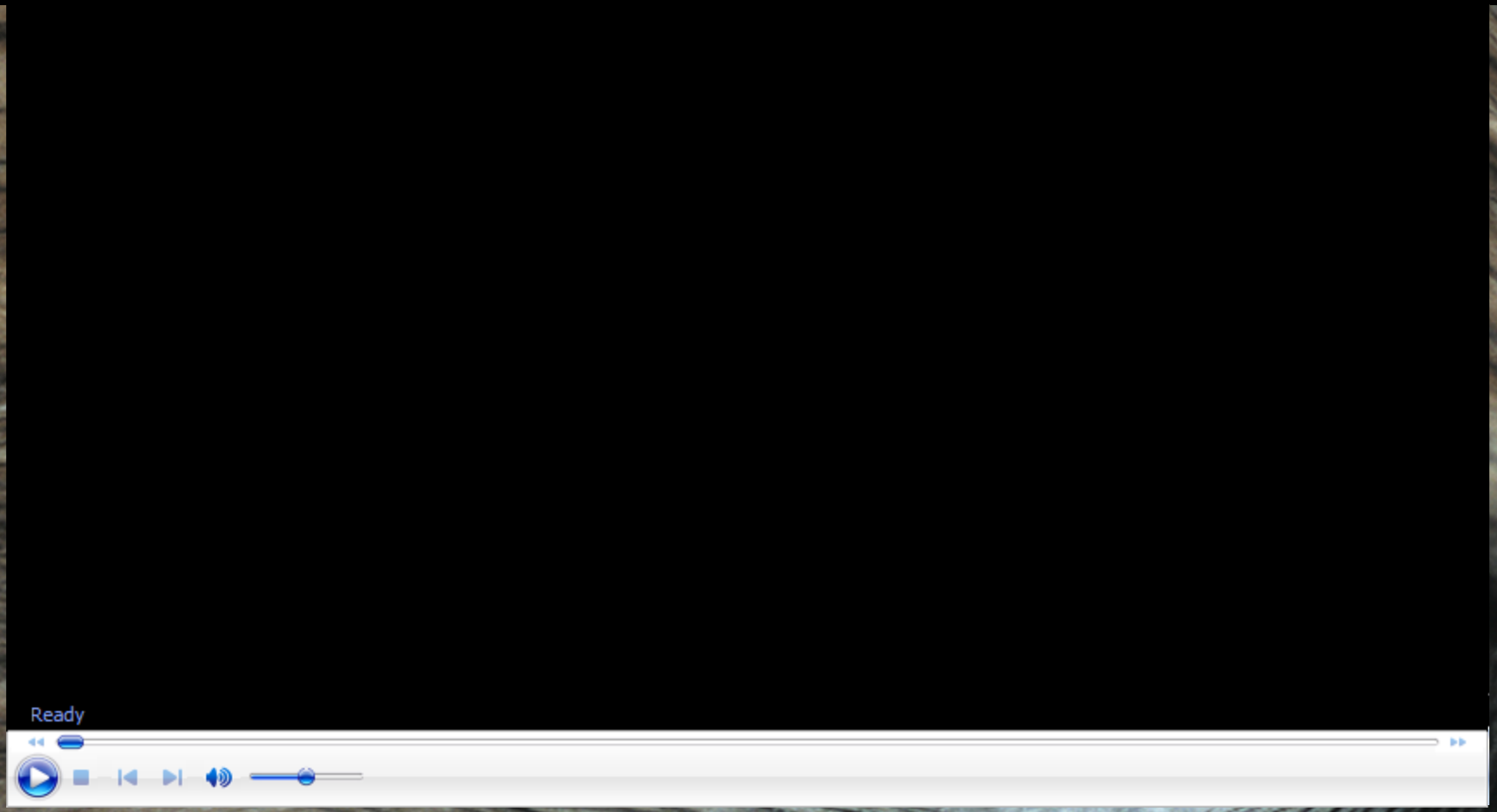


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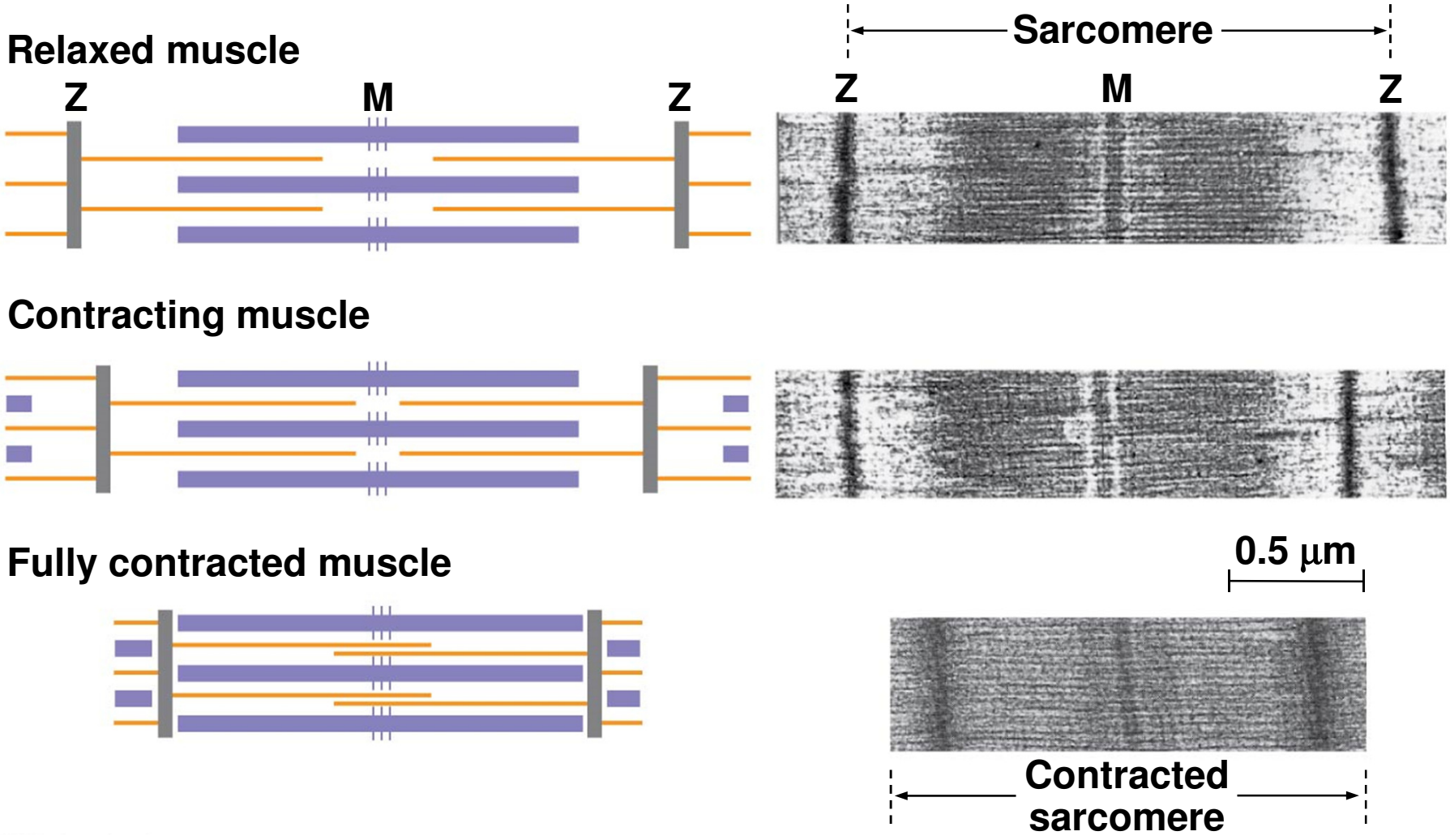
Figure 39.3


Relaxed muscle
Z
M
Z
Sarcomere
Z
M
Z
Contracting muscle
Fully contracted muscle
0.5 μm
Contracted sarcomere

CAMPBELL BIOLOGY IN FOCUS

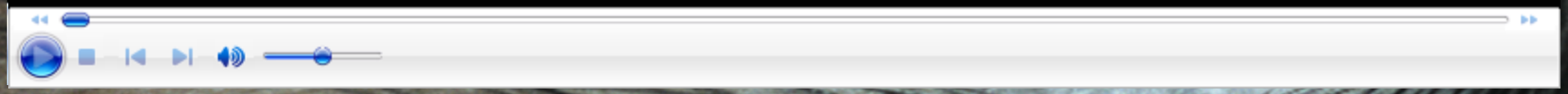


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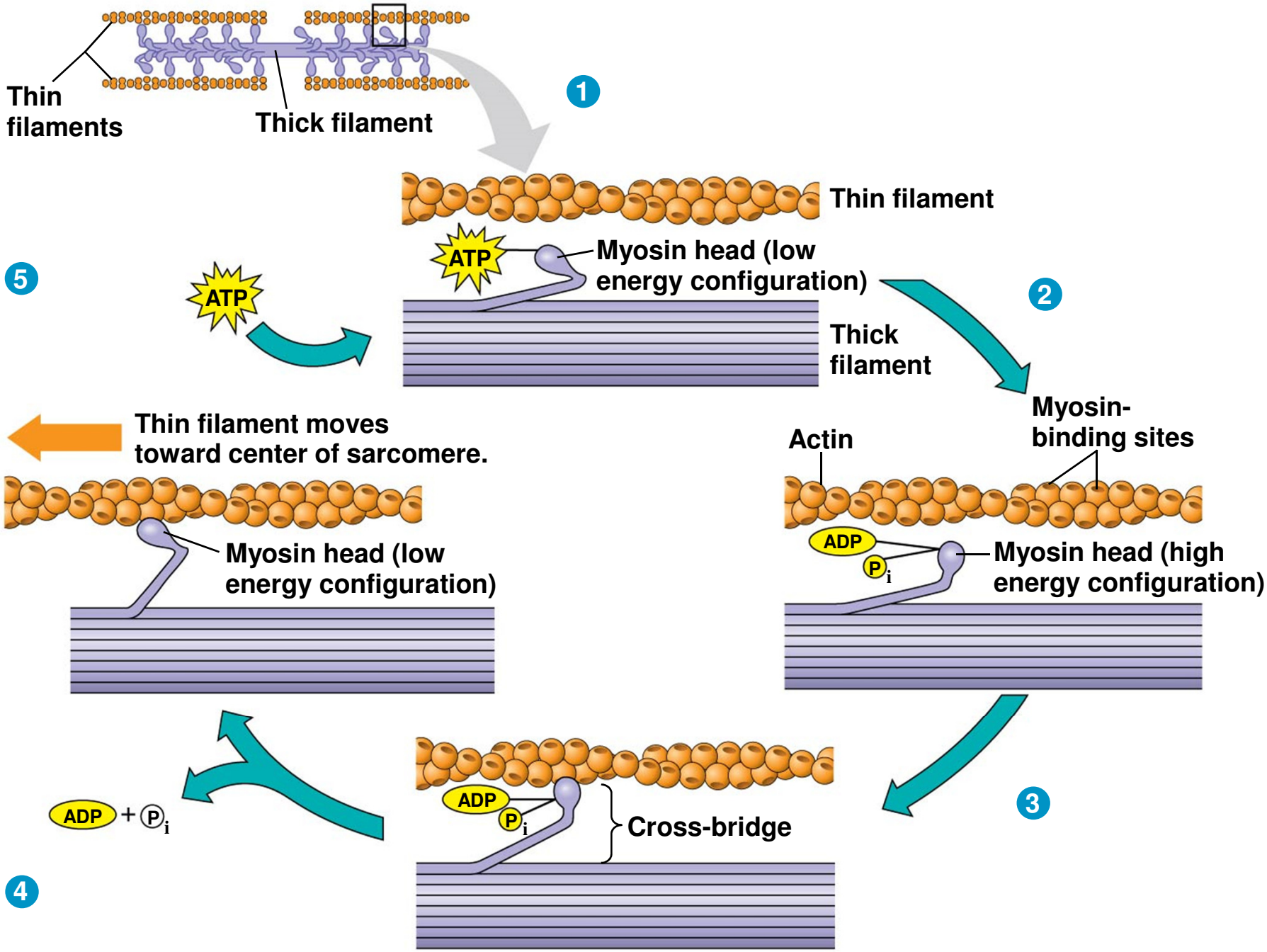
Figure 39.4

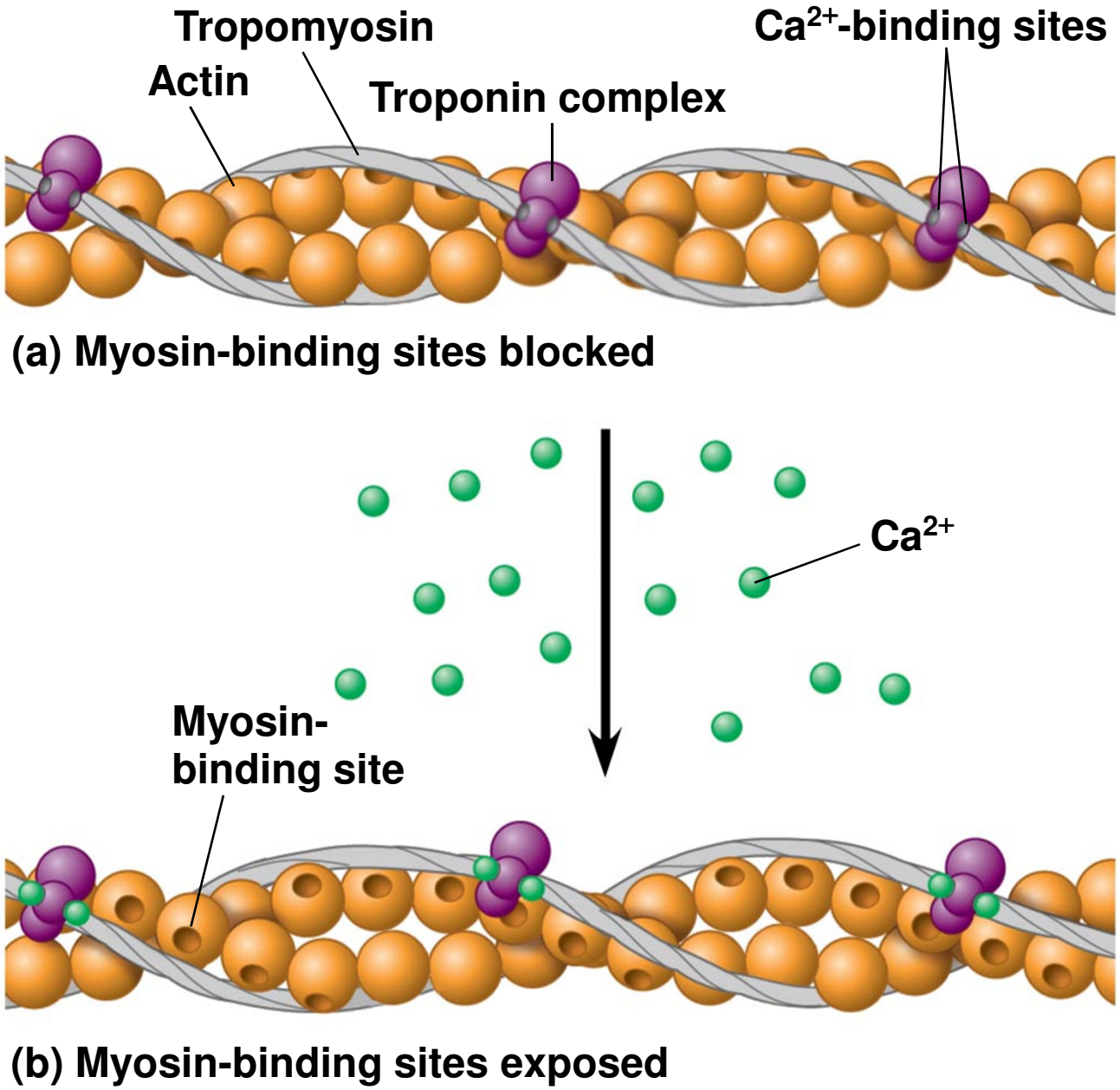

Thin filaments
Thick filament
1
Thin filament
ATP
Myosin head (low energy configuration)
Thick filament
2
Myosin-binding sites
Actin
ADP
Pi
Myosin head (high energy configuration)
3
Cross-bridge
ADP
Pi
4
ADP + Pi
Myosin head (low energy configuration)
Thin filament moves toward center of sarcomere.
5
ATP

The Role of Calcium and Regulatory Proteins

- Calcium ions and proteins bound to actin play crucial roles in muscle contraction and relaxation
- The regulatory protein **tropomyosin** and the **troponin complex**, a set of additional proteins, bind to actin strands on thin filaments when a muscle fiber is at rest
  - Tropomyosin covers myosin-binding sites along thin filament
  - Prevents actin and myosin from interacting

- For a muscle fiber to contract, myosin-binding sites must be uncovered
- This occurs when calcium ions (Ca^{2+}) bind to the troponin complex and expose the myosin-binding sites
  - Contraction occurs when the concentration of Ca^{2+} is high
  - Muscle fiber contraction stops when the concentration of Ca^{2+} is low

Figure 39.5


Tropomyosin
Actin
Troponin complex
Ca^{2+}-binding sites
(a) Myosin-binding sites blocked
Ca^{2+}
Myosin-
binding site
(b) Myosin-binding sites exposed

- The stimulus leading to contraction of a muscle fiber is an action potential in a motor neuron that makes a synapse with the muscle fiber
  - The synaptic terminal of the motor neuron releases the neurotransmitter acetylcholine
  - Acetylcholine depolarizes the muscle, causing it to produce an action potential

- Action potentials travel to the interior of the muscle fiber along **transverse (T) tubules**
  - Infoldings of the plasma membrane
- The action potential along T tubules causes the release of Ca^{2+} by **sarcoplasmic reticulum (SR)**
  - A specialized endoplasmic reticulum
- The Ca^{2+} binds to the troponin complex on the thin filaments, initiating muscle fiber contraction

- When motor neuron input stops, the muscle cell relaxes
  - Transport proteins in the SR pump Ca^{2+} out of the cytosol
  - Regulatory proteins bound to thin filaments shift back to the myosin-binding sites

Figure 39.6a

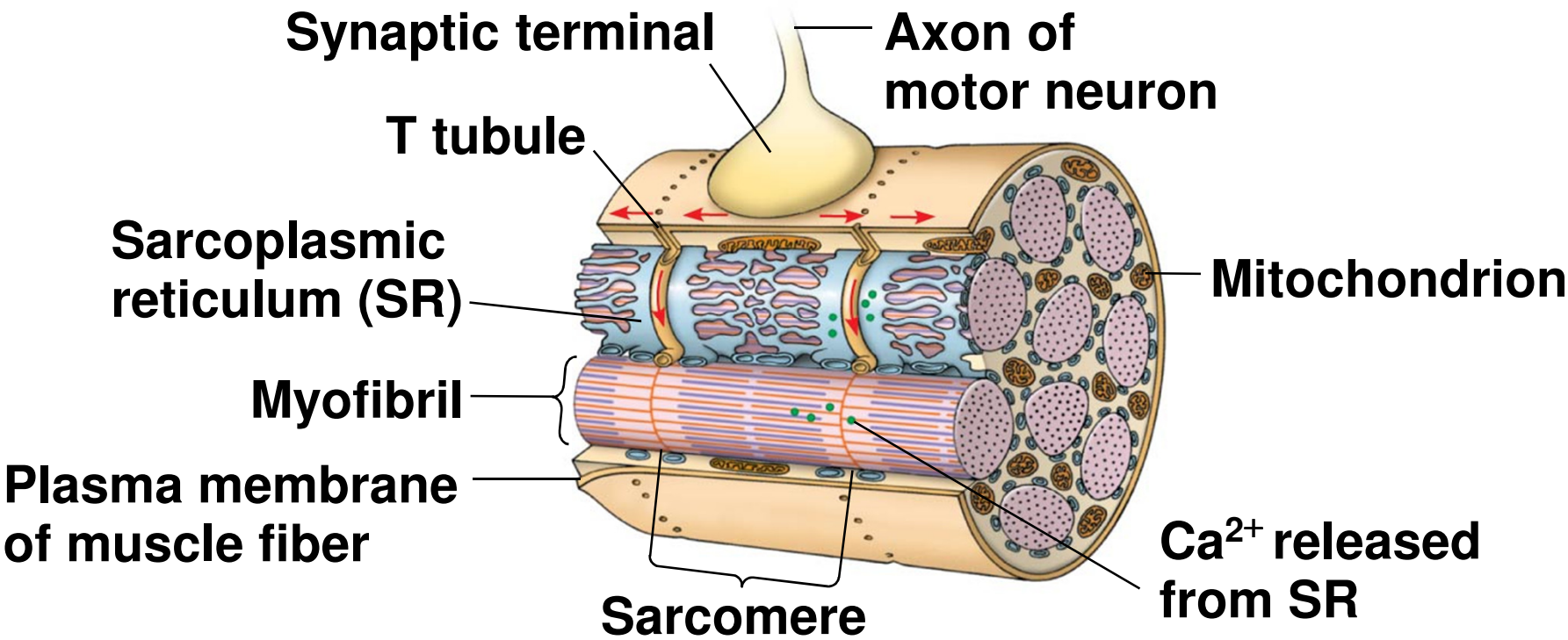
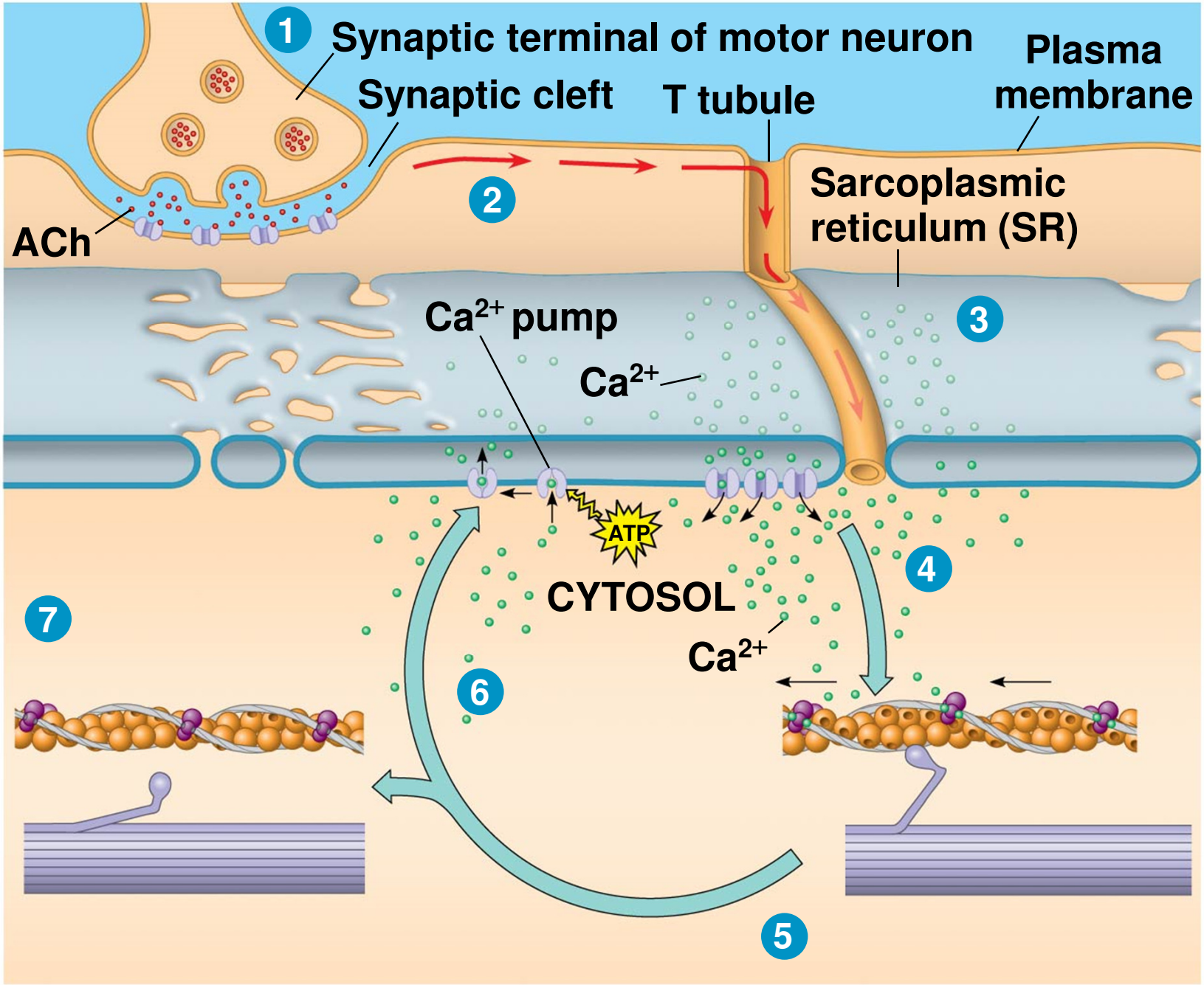
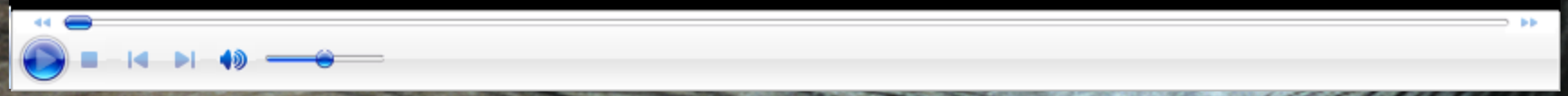

Synaptic terminal
Axon of motor neuron
T tubule
Sarcoplasmic reticulum (SR)
Mitochondrion
Myofibril
Plasma membrane of muscle fiber
Ca^{2+} released from SR
Sarcomere

Figure 39.6b


1
Synaptic terminal of motor neuron
Synaptic cleft
T tubule
Plasma membrane
ACh
2
Sarcoplasmic reticulum (SR)
3
Ca2+ pump
Ca2+
ATP
4
CYTOSOL
Ca2+
7
6
5

CAMPBELL BIOLOGY IN FOCUS



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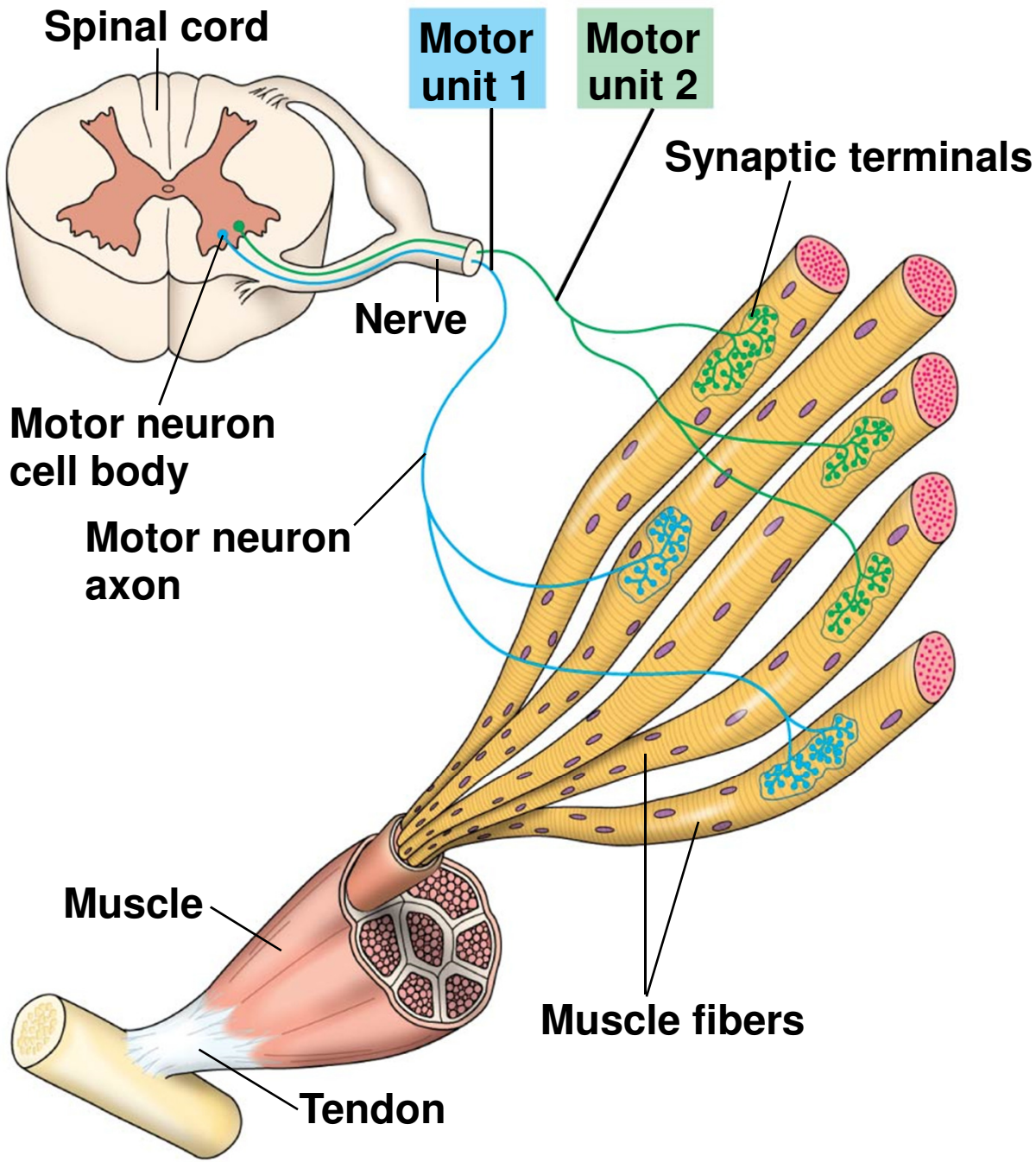
Nervous Control of Muscle Tension

- Contraction of an individual muscle fiber is a brief all-or-none twitch
- But contraction of a whole muscle is graded
  - Extent and strength of its contraction can be voluntarily altered
- There are two basic mechanisms by which the nervous system produces graded contractions
  - Varying the number of fibers that contract
  - Varying the rate at which fibers are stimulated

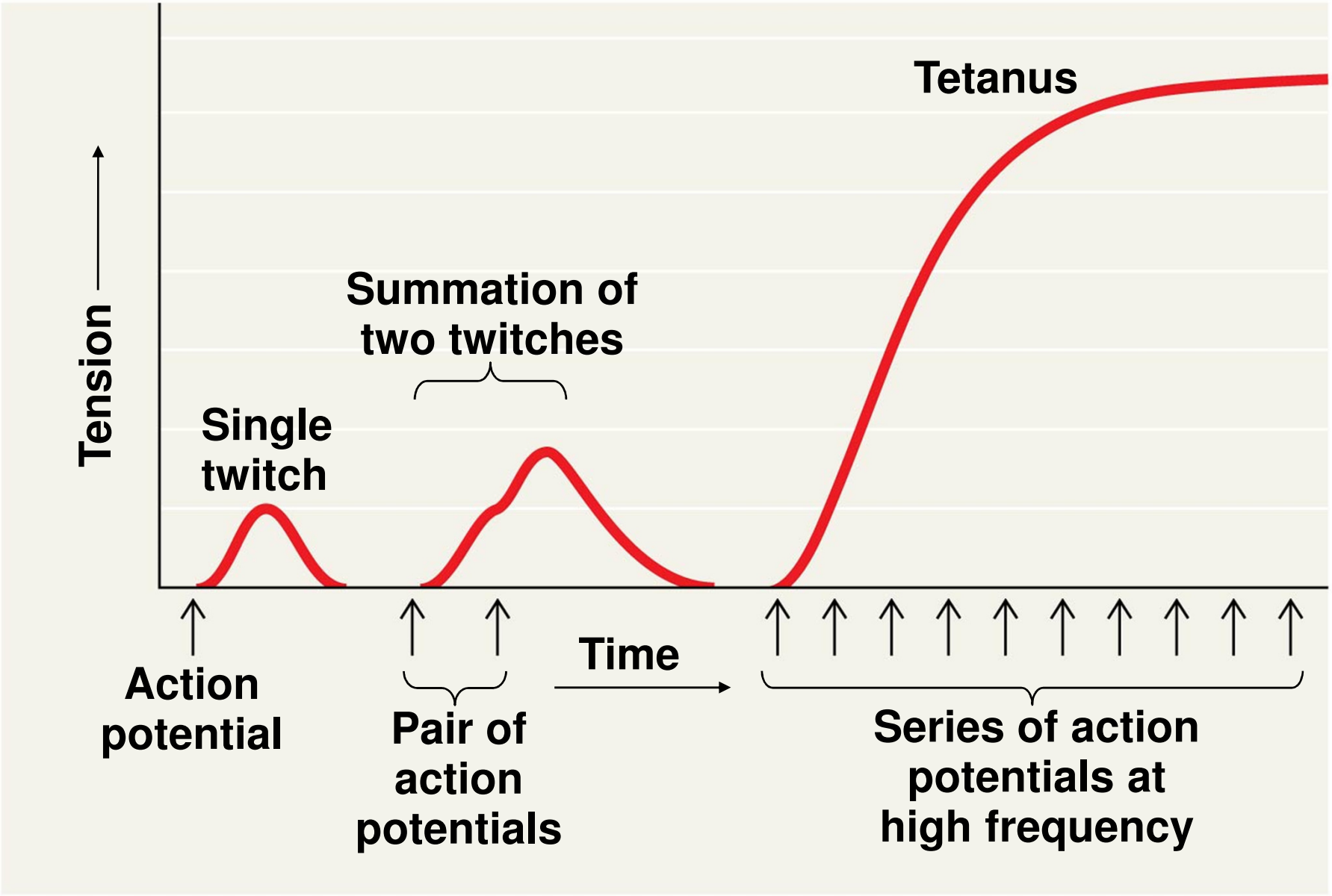
- In vertebrates, each motor neuron may synapse with multiple muscle fibers
  - But each fiber is controlled by only one motor neuron
- A **motor unit** consists of a single motor neuron and all the muscle fibers it controls
- *Recruitment* of multiple motor neurons results in stronger contractions

Figure 39.7


Spinal cord
Motor unit 1
Motor unit 2
Synaptic terminals
Nerve
Motor neuron cell body
Motor neuron axon
Muscle
Muscle fibers
Tendon

- A twitch results from a single action potential in a motor neuron
- More rapidly delivered action potentials produce a graded contraction by summation
- **Tetanus** is a state of smooth and sustained contraction produced when motor neurons deliver a volley of action potentials

Figure 39.8


Tetanus
Summation of two twitches
Single twitch
Tension
Action potential
Pair of action potentials
Time
Series of action potentials at high frequency

Types of Skeletal Muscle Fibers

- There are several distinct types of skeletal muscles, each of which is adapted to a particular set of functions
- They are classified by
  - The source of ATP powering the muscle activity
  - The speed of muscle contraction

Table 39.1 Types of Skeletal Muscle Fibers

	Slow Oxidative	Fast Oxidative	Fast Glycolytic
Contraction speed	Slow	Fast	Fast
Major ATP source	Aerobic respiration	Aerobic respiration	Glycolysis
Rate of fatigue	Slow	Intermediate	Fast
Mitochondria	Many	Many	Few
Myoglobin content	High (red muscle)	High (red muscle)	Low (white muscle)

Oxidative vs glycolytic fibers

- Differentiated by their energy source
  - Oxidative fibers rely mostly on aerobic respiration to generate ATP
    - Have many mitochondria, a rich blood supply, and a large amount of **myoglobin**
      - Myoglobin is a protein that binds oxygen more tightly than hemoglobin does
  - Glycolytic fibers use glycolysis as their primary source of ATP
    - Have less myoglobin than oxidative fibers and tire more easily

Fast-twitch and slow-twitch fibers

- Differentiated by their speed of contraction
  - **Slow-twitch fibers** contract more slowly but sustain longer contractions
    - All slow-twitch fibers are oxidative
  - **Fast-twitch fibers** contract more rapidly but sustain shorter contractions
    - Fast-twitch fibers can be either glycolytic or oxidative

Other Types of Muscle

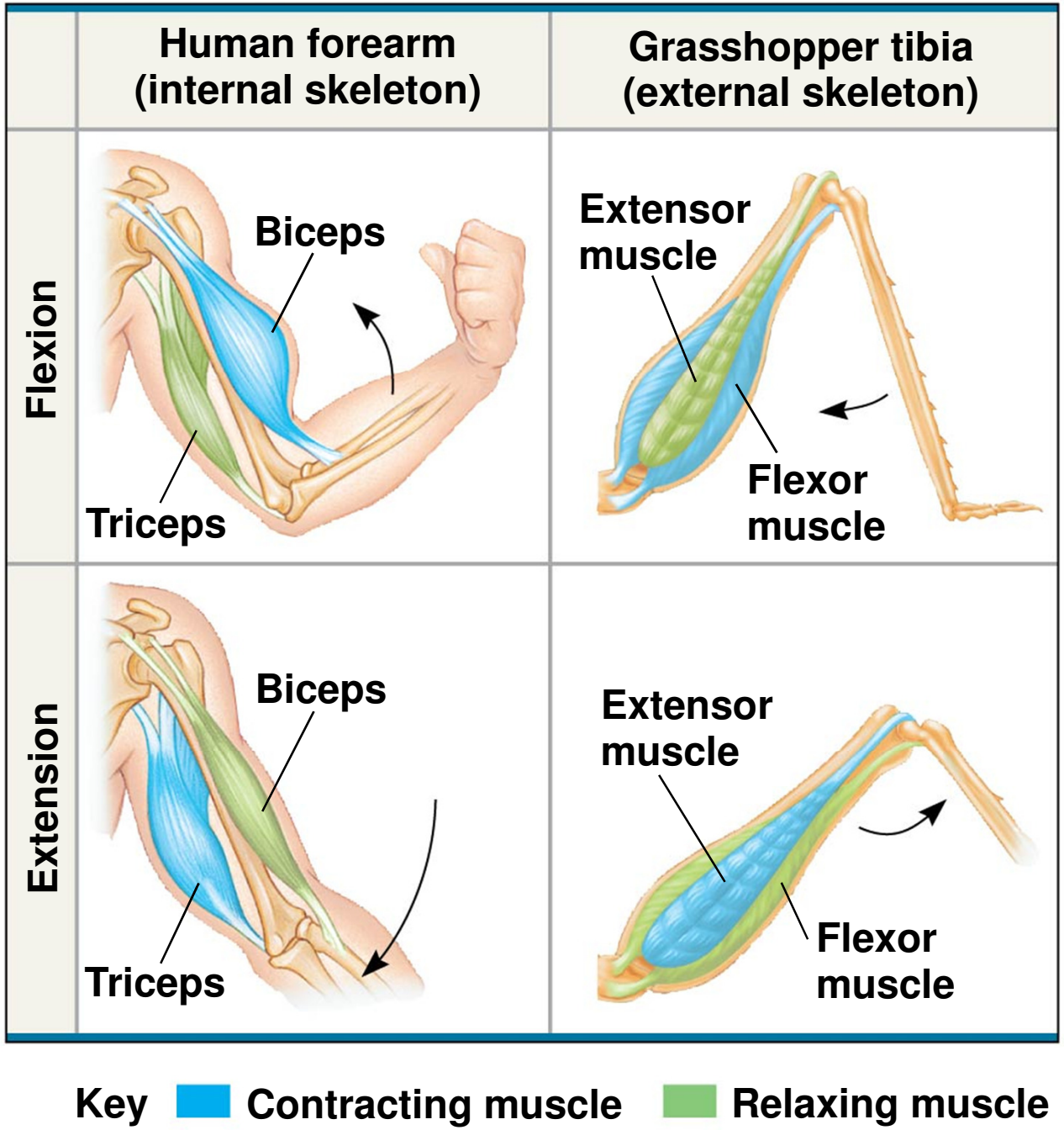
- In addition to skeletal muscle, vertebrates have cardiac muscle and smooth muscle
- **Cardiac muscle** is found only in the heart
  - Consists of striated cells electrically connected by specialized junctions called **intercalated disks**
  - Can generate action potentials without neural input
  - Action potential generated by specialized cells in one part of heart can spread to all other cardiac muscle cells, causing whole heart to contract

- **Smooth muscle** is found mainly in walls of hollow organs such as those of the digestive tract and blood vessels
  - Contractions are relatively slow and may be initiated by the muscles themselves
  - Contractions may also be caused by stimulation from neurons in the autonomic nervous system

Concept 39.2: Skeletal systems transform muscle contraction into locomotion

- Skeletal muscles are attached in antagonistic pairs, the actions of which are coordinated by the nervous system
  - Ex: Biceps and triceps
- The skeleton provides a rigid structure to which muscles attach
- Skeletons function in support, protection, and movement

Figure 39.10


Human forearm
(internal skeleton)
Grasshopper tibia
(external skeleton)
Flexion
Extension
Biceps
Triceps
Extensor muscle
Flexor muscle
Biceps
Triceps
Extensor muscle
Flexor muscle
Key
Contracting muscle
Relaxing muscle

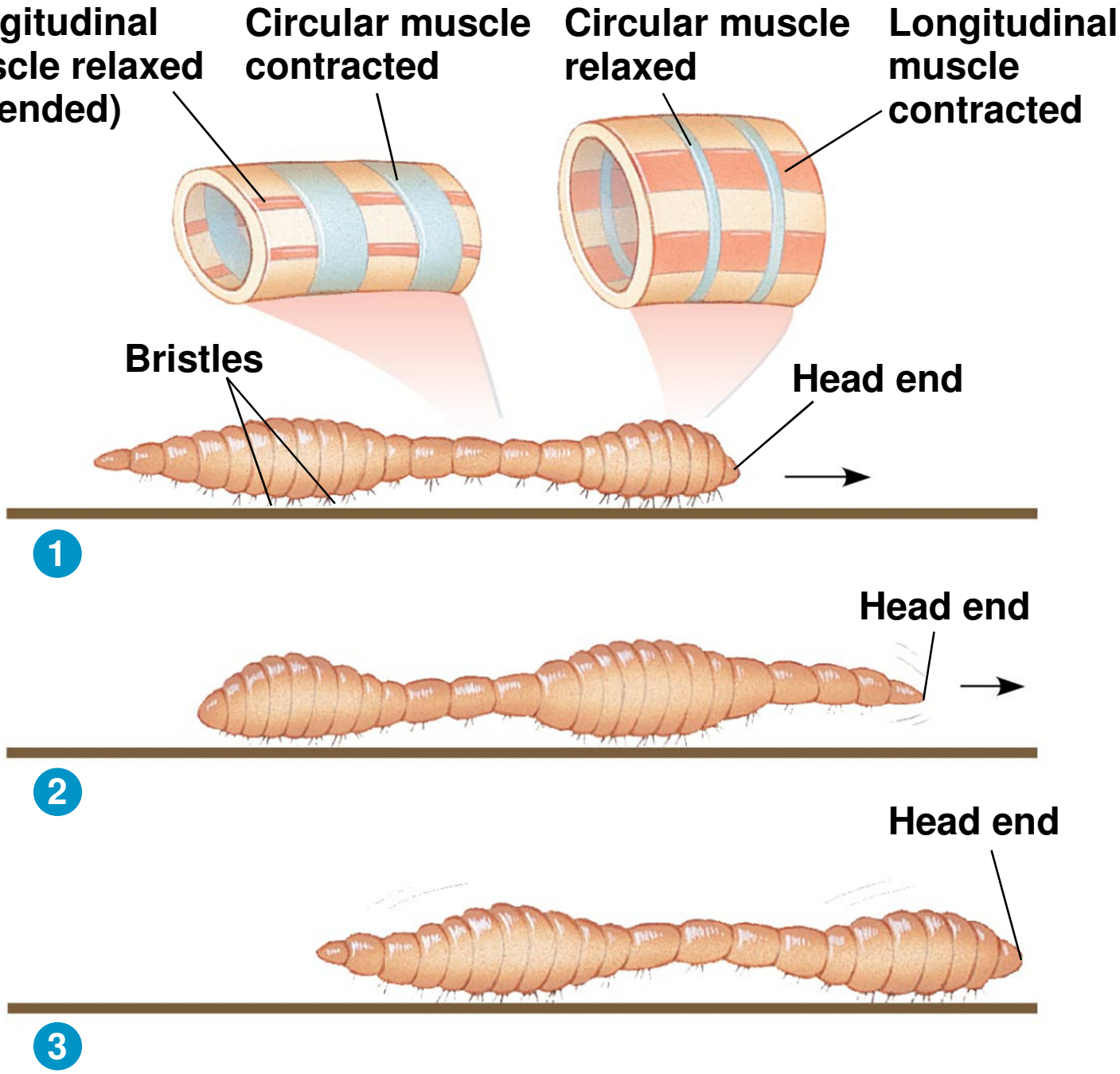
Types of Skeletal Systems

- The three main types of skeletons are
  - Hydrostatic skeletons (lack hard parts)
  - Exoskeletons (external hard parts)
  - Endoskeletons (internal hard parts)

Hydrostatic Skeletons

- A **hydrostatic skeleton** consists of fluid held under pressure in a closed body compartment
  - Main type of skeleton in most cnidarians, flatworms, nematodes, and annelids
- Annelids use their hydrostatic skeleton for **peristalsis**
  - A type of movement on land produced by rhythmic waves of muscle contractions

Figure 39.11


Longitudinal muscle relaxed (extended)
Circular muscle contracted
Circular muscle relaxed
Longitudinal muscle contracted
Bristles
Head end
1
Head end
2
Head end
3

Exoskeletons

- An **exoskeleton** is a hard encasement deposited on the surface of an animal
  - Found in most molluscs and arthropods
- Arthropods have a jointed exoskeleton called a *cuticle*
  - Can be both strong and flexible
  - Consists of a polysaccharide called **chitin**
- An arthropod must shed and regrow its exoskeleton when it grows

Endoskeletons

- An **endoskeleton** consists of a hard internal skeleton, buried in soft tissue
  - Found in organisms ranging from sponges to mammals
- Chordates have endoskeleton consisting of cartilage, bone, or some combo of the two

Size and Scale of Skeletons

- An animal's body structure must support its size
  - The skeletons of small and large animals have different proportions
- Body posture (position of legs relative to main body) is more important than leg size

Types of Locomotion

- Most animals are capable of **locomotion**
  - Active travel from place to place
- In locomotion, energy is expended to overcome friction and gravity

- Flying
  - Wing shape is key
  - Low body mass
- Locomotion on land
  - Powerful muscles and strong skeletal support
  - Balance
- Swimming
  - Streamlined shape

Concept 39.3: Discrete sensory inputs can stimulate both simple and complex behaviors

- Niko Tinbergen identified four questions that should be asked about animal behavior
  1. What stimulus elicits the behavior, and what physiological mechanisms mediate the response?
  2. How does the animal's experience during growth and development influence the response?
  3. How does the behavior aid survival and reproduction?
  4. What is the behavior's evolutionary history?

- **Behavioral ecology** is the study of the ecological and evolutionary basis for animal behavior
  - Integrates proximate and ultimate explanations for animal behavior
- *Proximate causation* addresses “how” a behavior occurs or is modified
  - Questions 1 and 2
- *Ultimate causation* addresses “why” a behavior occurs in the context of natural selection
  - Questions 3 and 4

Fixed Action Patterns

- A **fixed action pattern** is a sequence of unlearned, innate behaviors that is unchangeable
  - Once initiated, it is usually carried to completion
- A fixed action pattern is triggered by an external cue known as a **sign stimulus**

Migration

- Environmental cues can trigger movement in a particular direction
- **Migration** is a regular, long-distance change in location
- Animals can orient themselves using
  - The position of the sun and their *circadian clock*, an internal 24-hour activity rhythm or cycle
  - The position of the sun or stars
  - Earth's magnetic field

Behavioral Rhythms

- Some animal behavior is affected by the animal's circadian rhythm, a daily cycle of rest and activity
- Behaviors such as migration and reproduction are linked to changing seasons, or a *circannual rhythm*
- Daylight and darkness are common seasonal cues
- Some behaviors are linked to lunar cycles, which affect tidal movements

Animal Signals and Communication

- In behavioral ecology, a **signal** is a behavior that causes a change in another animal's behavior
- **Communication** is the transmission and reception of signals

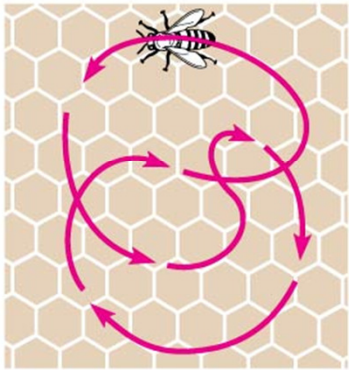
Forms of Animal Communication

- 4 common modes of animal communication:
  - Visual
  - Chemical
  - Tactile
  - Auditory
- Most terrestrial animals are nocturnal
  - Visual displays are relatively ineffective
  - Rely on olfactory and auditory signals
- Diurnal animals (active during daytime) like birds
  - Communicate primarily by visual and auditory signals

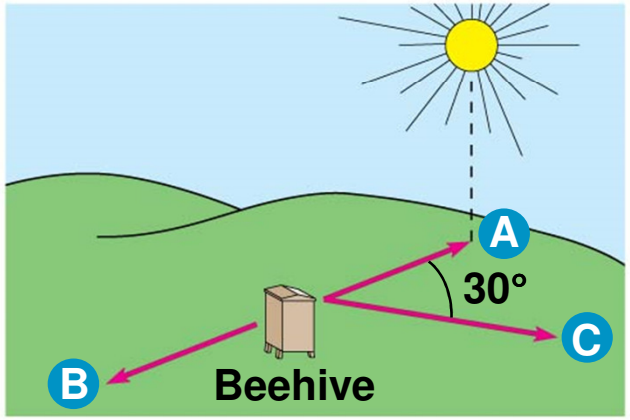
- In a *stimulus-response chain*, the response to each stimulus is the stimulus for the next behavior
- Honeybees show complex communication with symbolic language
  - A bee returning from the field performs a dance to communicate information about the distance and direction of a food source

Figure 39.16

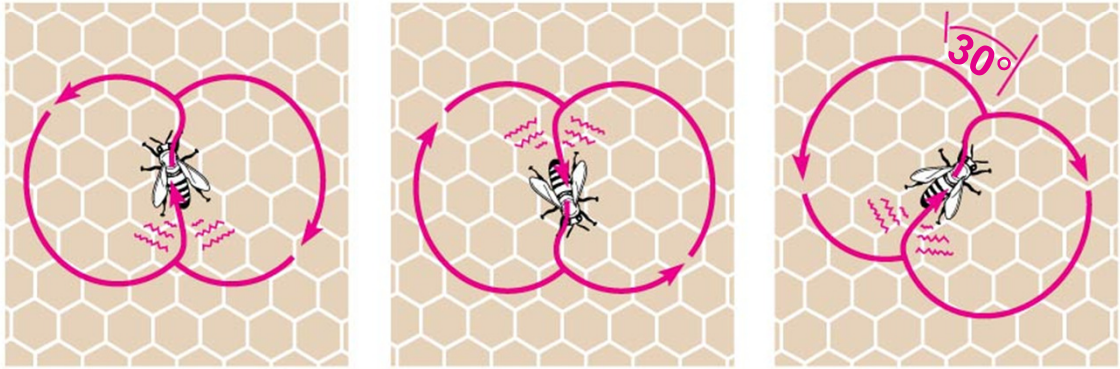
(a) Worker bees



(b) Round dance (food near)



(c) Waggle dance (food distant)



Location A

Location B

Location C

Pheromones

- Many animals that communicate through odors emit chemical substances called **pheromones**
  - Often relate to reproductive behavior
  - Can serve as alarm signals
- Pheromones serve in communication between animals of the same species!

Concept 39.4: Learning establishes specific links between experience and behavior

- **Innate behavior** is developmentally fixed and does not vary among individuals
  - Examples
    - Fixed action patterns
    - Courtship stimulus-response chain
    - Pheromone signaling

Experience and Behavior

- Cross-fostering studies help behavioral ecologists to identify the contribution of environment to an animal's behavior
- A **cross-fostering study** places the young from one species in the care of adults from another species
- In humans, **twin studies** allow researchers to compare the relative influences of genetics and environment on behavior

- **Learning** is the modification of behavior based on specific experiences

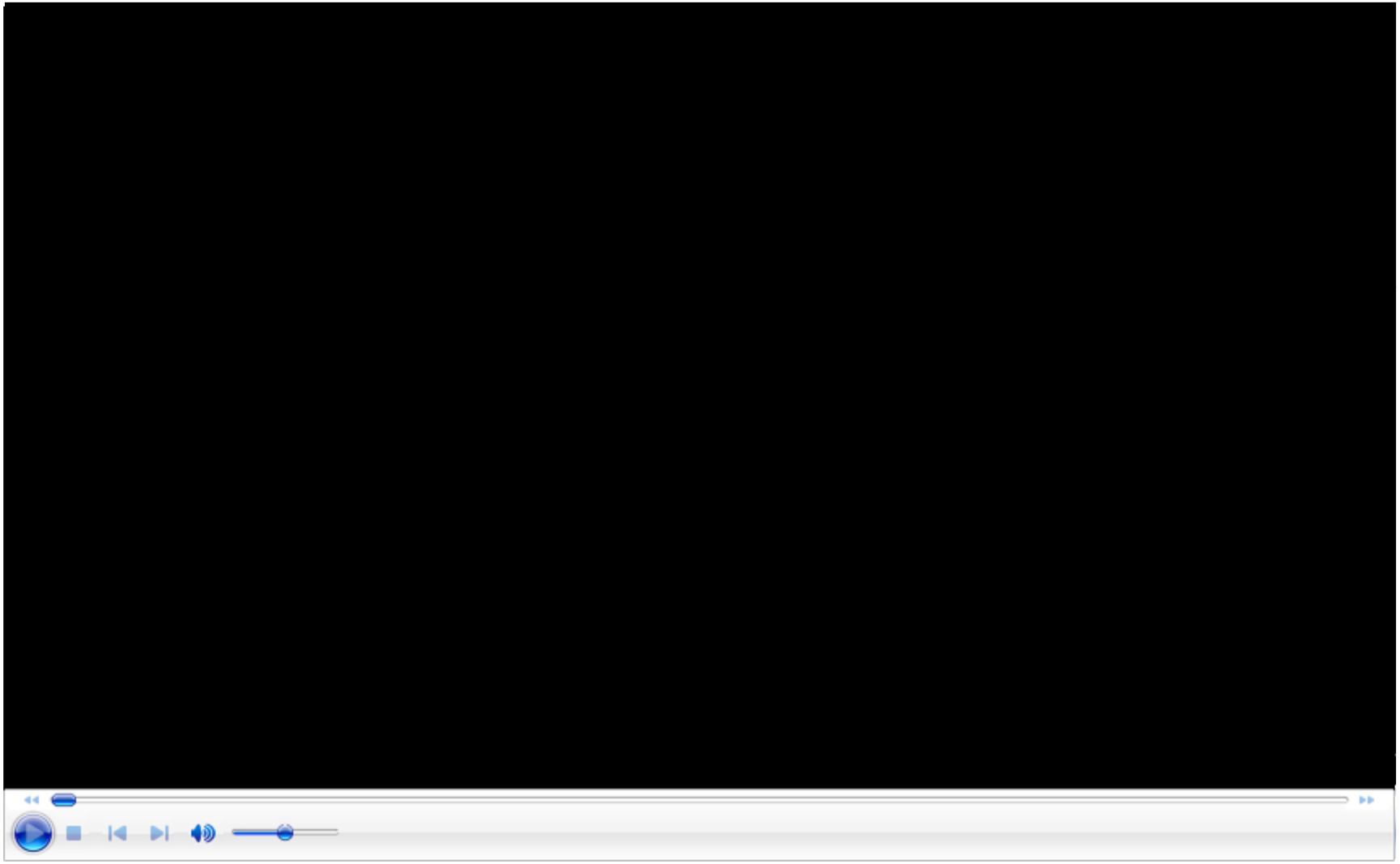
Imprinting

- **Imprinting** is the establishment of a long-lasting behavioral response to a particular individual
- Imprinting can only take place during a specific time in development, called the **sensitive period**
  - A limited developmental phase that is the only time when certain behaviors can be learned
- An example of imprinting is young geese following their mother

Figure 39.17

(a) Konrad Lorenz and geese

(b) Pilot and cranes



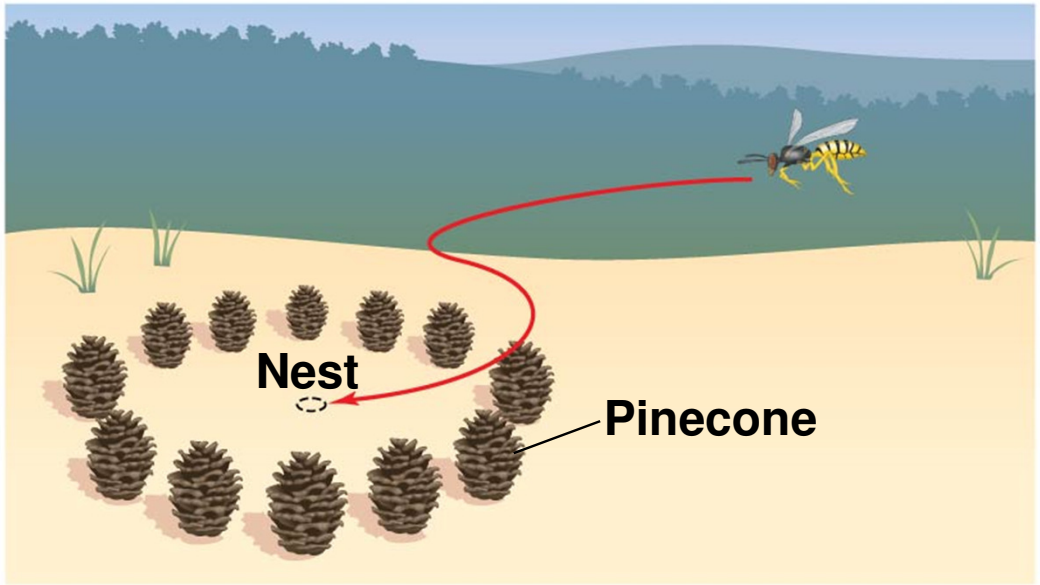
Video: Ducklings

Spatial Learning and Cognitive Maps

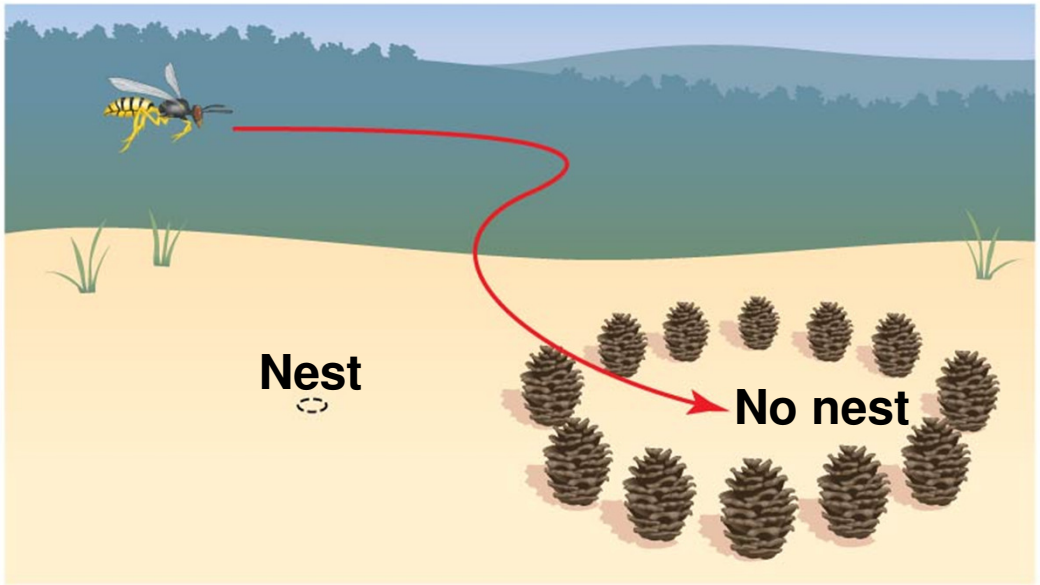
- **Spatial learning** is the establishment of a memory that reflects the spatial structure of the environment
  - Ex: Digger wasps use landmarks to find nest entrances
- A **cognitive map** is an internal representation of spatial relationships between objects in an animal's surroundings
  - Ex: Clark's nutcrackers can find food hidden in caches located halfway between particular landmarks

Figure 39.18

Experiment



Results



Associative Learning

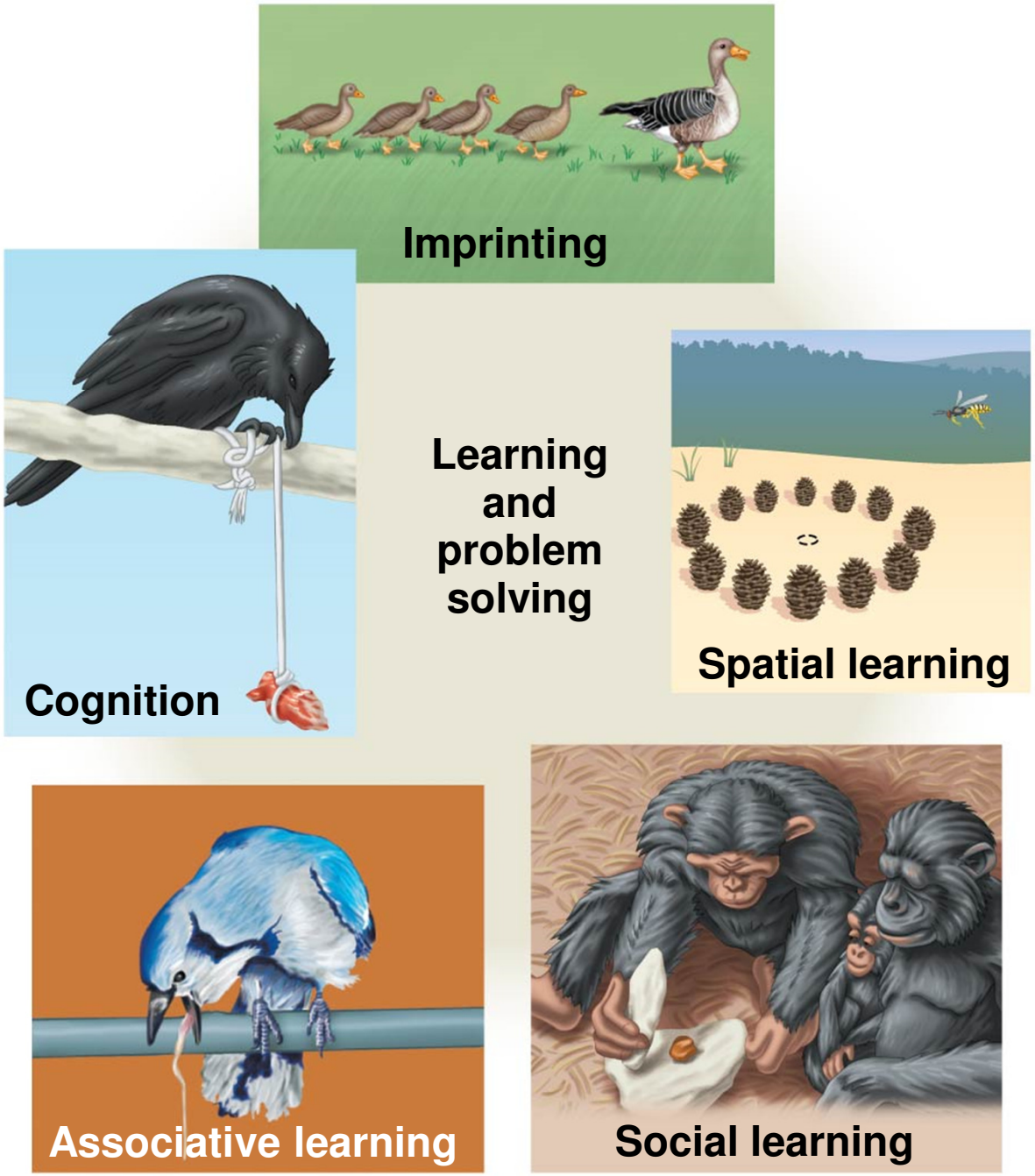
- In **associative learning**, animals associate one feature of their environment with another
  - Ex: Associating color with foul taste
    - Blue jays will avoid eating butterflies with specific colors after a bad experience with a distasteful monarch butterfly

Cognition and Problem Solving

- **Cognition** is a process of knowing that may include awareness, reasoning, recollection, and judgment
  - Ex: Honeybees can distinguish “same” from “different”
- **Problem solving** is the process of devising a strategy to overcome an obstacle
  - Ex: Chimpanzees can stack boxes in order to reach suspended food
  - Ex: Ravens obtained food suspended from a branch by a string by pulling up the string

- **Social learning** is learning through the observation of others and forms the roots of culture
  - Ex: Young chimpanzees learn to crack palm nuts with stones by copying older chimpanzees
- **Culture** is a system of information transfer through observation or teaching that influences behavior of individuals in a population
  - Can alter behavior and influence the fitness of individuals

Figure 39.UN03



Concept 39.5: Selection for individual survival and reproductive success can explain most behaviors

- Behavior enhances survival and reproductive success in a population
- **Foraging** is a food-obtaining behavior
  - Includes recognizing, capturing, and eating food items
  - Essential for survival and reproduction!

Mating Behavior and Mate Choice

- Mating behavior and mate choice play a major role in determining reproductive success
  - Includes seeking or attracting mates
  - Choosing among potential mates
  - Competing for mates
  - Caring for offspring

Mating Systems and Sexual Dimorphism

- The mating relationship between males and females varies greatly from species to species
- In some species there are no strong pair-bonds
- In **monogamous** relationships, one male mates with one female
  - Males and females with monogamous mating systems often look similar

- In **polygamous** relationships, an individual of one sex mates with several individuals of the other sex
  - Species with polygamous mating systems usual exhibit *sexual dimorphism*
    - Males and females differ in appearance
- Polygamous relationships can be either polygynous or polyandrous
  - In *polygyny*, one male mates with many females
    - Males are usually more showy and larger than females
  - In *polyandry*, one female mates with many males
    - Females are often more showy than males

Figure 39.21

(a) Monogamous species

(b) Polygynous species

(c) Polyandrous species

Mating Systems and Parental Care

- Needs of the young are an important factor constraining evolution of mating systems
- Consider bird species where chicks need a continuous supply of food
  - A male maximizes his reproductive success by staying with his mate and caring for his chicks (monogamy)
- Consider bird species where chicks are soon able to feed and care for themselves
  - A male maximizes his reproductive success by seeking additional mates (polygyny)

- Certainty of paternity influences parental care and mating behavior
  - Females can be certain that eggs laid or young born contain her genes
  - However, paternal certainty depends on mating behavior
    - Relatively low in species with internal fertilization because mating and birth are separated over time
      - Thus exclusively males parental care is rare in birds and mammals
    - Much higher when egg laying and mating occur together, as in external fertilization

Sexual Selection and Mate Choice

- Sexual dimorphism results from sexual selection, a form of natural selection
- In *intersexual selection*, members of one sex choose mates on the basis of certain traits
  - Such as courtship songs
- *Intrasexual selection* involves competition between members of the same sex for mates
  - May involve *agonistic behavior*
    - An often ritualized contest that determines which competitor gains access to a resource

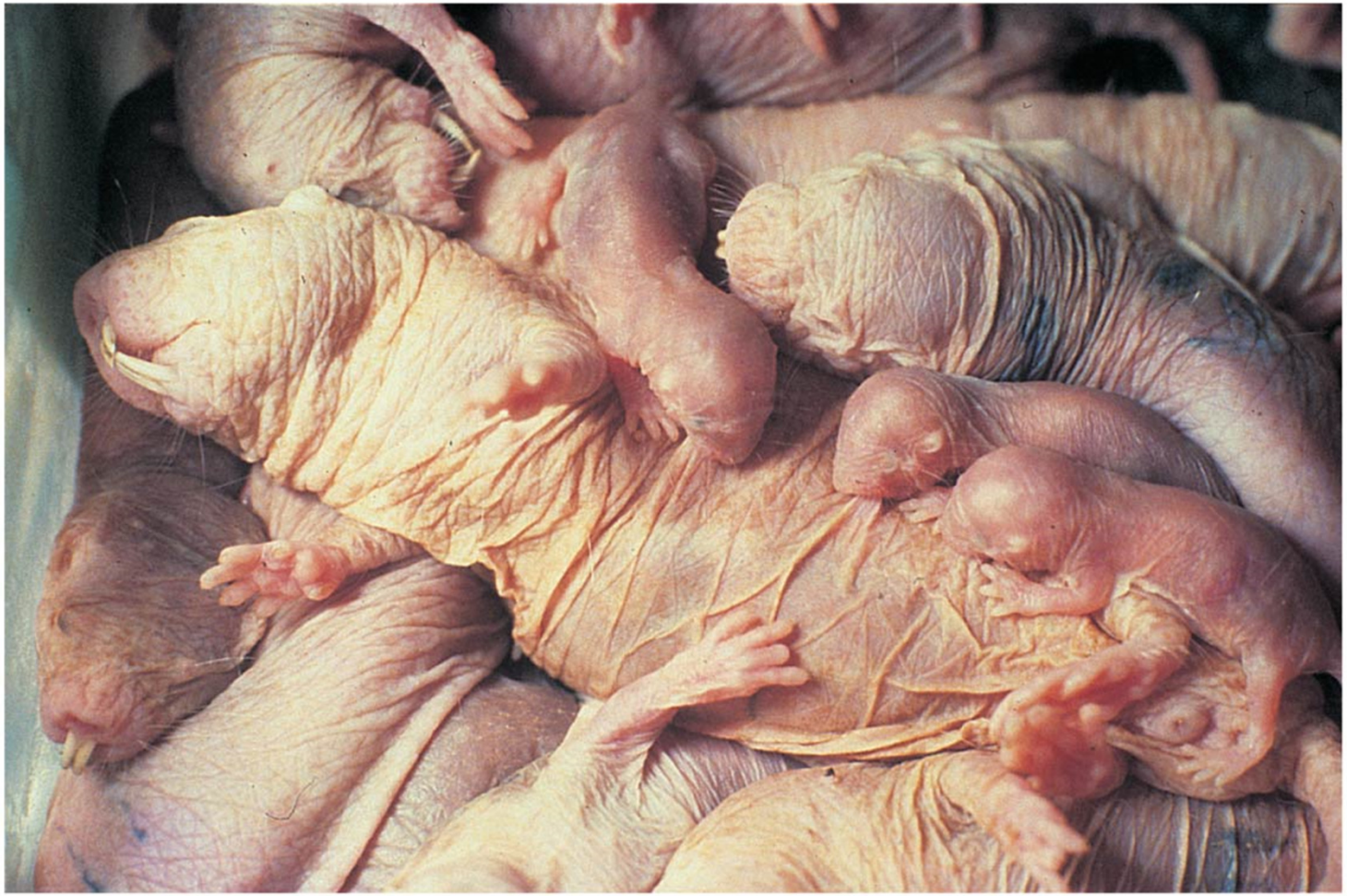
Concept 39.6: Inclusive fitness can account for the evolution of behavior, including altruism

- The definition of fitness can be expanded beyond individual survival to help explain “selfless” behavior

Altruism

- Natural selection favors behavior that maximizes an individual's survival and reproduction
  - These behaviors are often selfish
- On occasion, some animals behave in ways that reduce their individual fitness but increase the fitness of others
  - Called **altruism**, or selflessness
  - Ex: Ground squirrel will make an alarm to warn others of a predator, even though the noise increases its own chances of being killed
  - Ex: Nonreproductive naked mole rats may sacrifice their lives to protect reproductive queen form predators

Figure 39.26



Inclusive Fitness

- Altruism can be explained by inclusive fitness
- **Inclusive fitness** is the total effect an individual has on proliferating its genes by producing offspring and helping close relatives produce offspring
  - Consider parents sacrificing for their offspring
- **Kin selection** is natural selection that favors altruistic behavior by enhancing reproductive success of relatives
  - Weakens with hereditary distance